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A MULTI-WAVE ULTRASONIC PROBE AS A SUBSTITUTE FOR THE TANDEM TECHNIQUE

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ABSTRACT

Incomplete penetration in double-bevel welds, double-V welds, and T joints can be detected and its size estimated only with the tandem technique. Sometimes, however, the tandem technique cannot be readily used because of a complex specimen shape, particularly at sheets with wide surfacing welds and closed vessels. The estimation of a reflector size using the DGS method provides no useful results. A multi-wave ultrasonic probe and transformation of ultrasonic waves, however, may substitute for the tandem technique.

***Keywords**:* Multi-wave ultrasonic probe, Tandem technique

1. Testing of thin-walled welds: d = 6 - 25 mm

A plate of only 12 mm in thickness, a surfacing weld of 12 mm in width and the access to one surface only did not permit to use the tandem technique. The sole option was testing with a MWB 70 probe of 4 MHz and the estimation of the reflector size using DGS. According to the DGS method the reflector size was 3 mm, which means around 7 mm^2 of the reflecting surface. The reflector length being around 10 mm, which exceeds the sound-beam width, this means that the height of the incomplete penetration was 0.7 mm only. Such small discontinuities can be found in completely penetrated welds as well, and they are tolerated.

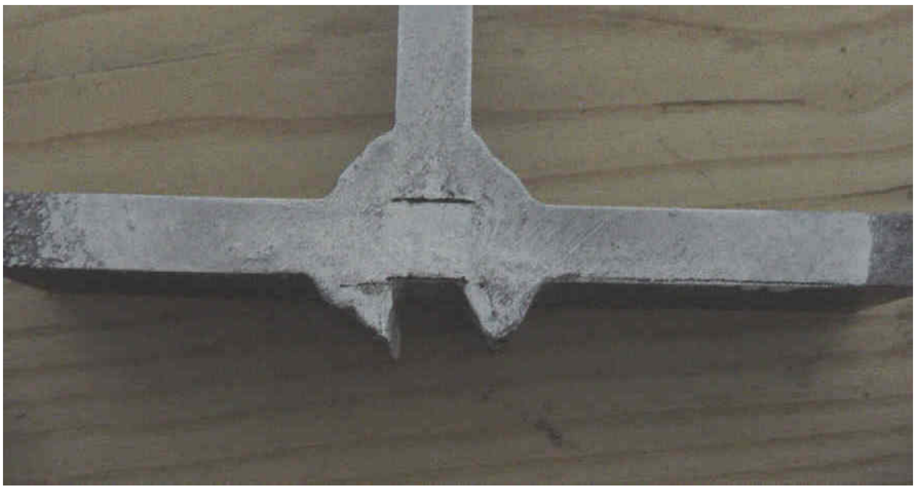


Fig. 1: Frame with cruciform joints failed because of having been only fillet-welded.

Figure 1 shows a welded structure with cruciform joints and a fillet weld, which failed in operation. Thus it was still not clear how the welds were produced, the knowledge of which was indispensable to be able to choose the right testing method.
The present study was initiated by an accident caused by a wall torn-off from the welded structure with cruciform joints:.

- test specimen: plate of 6 to 25 mm in thickness
- ultrasonic probe: type SEK4, 2x4 x9 mm, 4 MHz.

1.1 Wave transformation

The wave transformation at an iron/air boundary makes it possible to direct the reflected wave back to the point of incidence.
It was not certain whether the other parts of the structure were welded only at the joint assemblies or they were fully penetrated. There was no relevant documentation available.
A longitudinal wave has an angle of incidence of 76° and falls on a reflector at an angle of 14°. From here it reflects at the same angle as the longitudinal wave with an intensity of 85% of the sound amplitude (sensitivity) to the bottom wall where it transforms into a transverse wave and is then directed at an angle of 32° back to the incident surface with an intensity of around 80%. Here the wave is received by the same ultrasonic probe. In order to eliminate the dead zone, the measurement was performed with two equal probes enclosed in the same housing using the SE method.
Figure 2 shows a factor of sound reflection falling on the iron/air boundary at a certain angle.

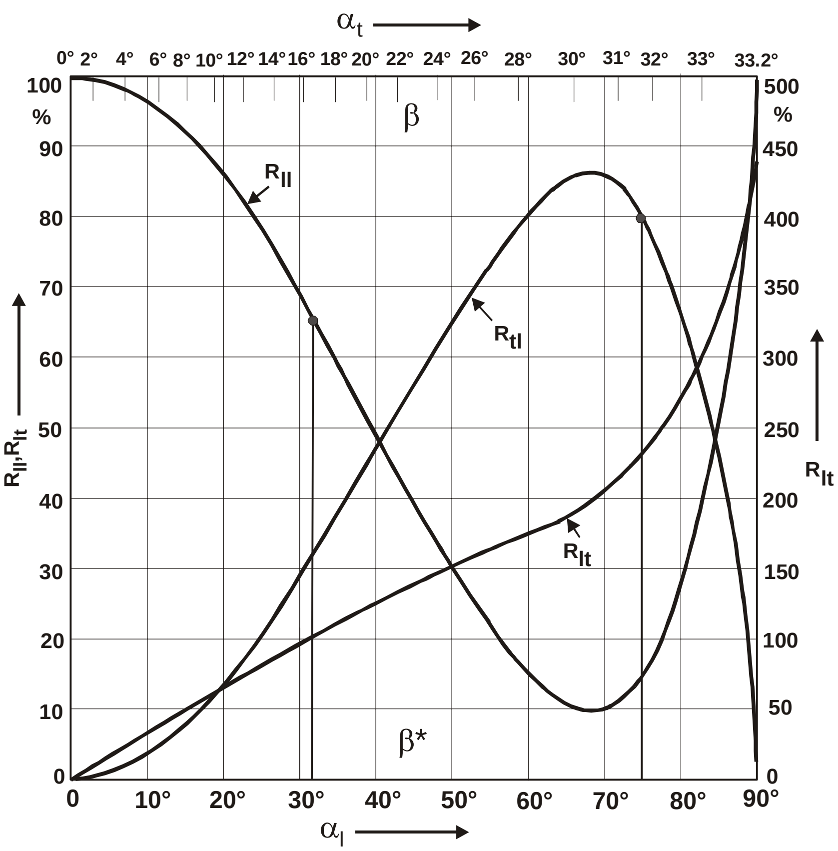


Fig. 2: Longitudinal wave strongly transforms into transversal wave in a range of angle of incidence of 60 to 80°.

1.2 Calculation of the total sound path

An approximate calculation:

$$S_{LT} = [1 : \cos\beta^{*} + (1 : \cos\beta) \text{ x } V_L / V_T - 1 \text{ x } \operatorname{tg}\beta\,] \text{ x d}$$
$$S_{LT} = [1 : \cos 76^{o} + (1 : \cos 32.2^{o}) \text{ x } 1.82 - 1 \text{ x } \operatorname{tg} 32.2^{o}\,] \text{ x d} = 5.65 \text{ x d} \tag{1}$$

where: d - the plate thickness, ß* - the angle of incidence of the longitudinal wave, ß - the angle of reflection of the transverse wave, V_L = 5920 m/s - the velocity of the longitudinal wave, V_T = 3250 m/s - the velocity of transverse waves and V_L/V_T = 1.82, the ratio between the velocities of wave propagation.

As the measurement range of the ultrasonic device was calibrated in the reflection technique and the measurement was performed in the SE technique, the result obtained should be divided by 2.

$$p = (5.65 \text{ x d}) : 2$$
$$p = 2.83 \text{ x d} \tag{2}$$

1.3 Distance of the reflector from the point of ultrasound incidence

Distance of the reflector from the point of ultrasound incidence can be obtained by

$$P = \text{d x } 2 \operatorname{tg}\beta = S_1 \text{ x } \sin\beta^{*}$$
$$P = \text{d} / 2 \text{ x } \operatorname{tg} 32^{o} = S_1 \text{ x } \sin 76^{o} = 2 \text{ x d} \tag{3}$$

The longitudinal wave provides a weak echo from the reflector. It is moving horizontally during the ultrasonic scanning and provides a datum on the distance between the reflector and the point of sound incidence P.

1.4 Estimation of the reflector size

The estimation of the reflector size is feasible if the sensibility calibration was performed at a square-cut test piece. The echo height will increase in a linear way to a reflector height of 10 mm because piezo-vibrators have a length of 10 mm. With thicker plates the echo will maintain the same height to a thickness of 14 mm, then it will start decreasing due to sound attenuation, particularly with the transverse wave. The estimation of the size reflector depends on a number of factors, particularly on the transfer losses. For example with a rusty surface or uneven surface 2 to 3 dB should be added to a clean rolled surface, if the sensibility calibration was performed at a clean surface of a lying test body V2. With rusty or strongly rough surfaces the correction should be determined by trials.

The angle of incidence should be maintained as accurate as possible, i.e., ± 1°. Consequently, the contact surface of the ultrasonic probe should be protected against wear with hard-metal inserts. An accurate estimation of the reflector size is possible only if the direction of the reflector is exactly perpendicular to the surface, the two plate surfaces being plane-parallel to each other.

Deviations from the above-mentioned prerequisites do not hinder locating of the reflector but the accurate estimation of the reflector size.

Figure 3 shows incomplete penetration in a fillet weld of a closed vessel that cannot be detected with a single ultrasonic angle probe and an estimation cannot be made because there is only one scanning face accessible.

With thicker plates ultrasonic probe SEK2 with vibrators (piezo 10 x 20 mm) is employed. A linear dependence of the echo height depends on a plate thickness of up to 20 mm.

As a contact medium with long welds water is applied. The latter is supplied through the probe to the contact surface between the probe and the test specimen.

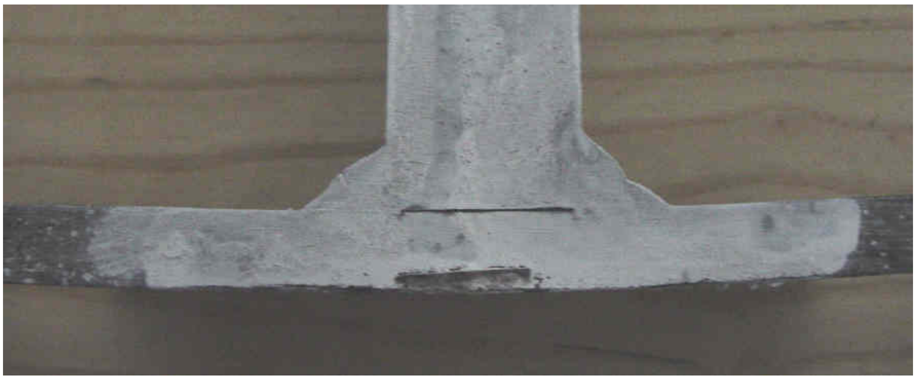
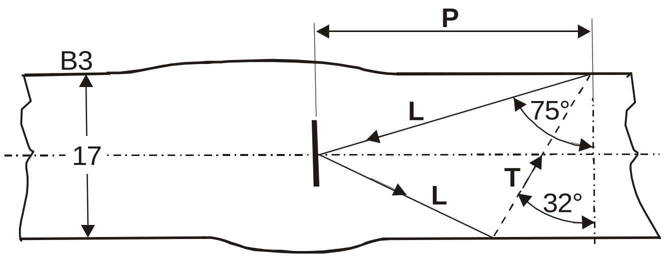


Fig. 3: Example of incomplete penetration in a fillet weld of closed vessel.

1.5 Practical example

The incomplete penetration in a 17 mm thick and 7 mm high weld (Fig. 4) can be detected only with an angle probe, only a reflector of 3 mm in size in accordance with DGS, which makes around 7 mm^2 of the reflection face, i.e., 0.7 mm in height, because it is longer than the ultrasound-beam width. A reflector perpendicular to the surface can be detected only with a multi-wave probe, particularly at a closed vessel or a thin wall. The 17 mm thick plate was welded without an appropriate weld preparation, thus a separation of 6 to 8 mm remained in the weld.



d = 17 mm
β' = 75°
S = 2.82 x d
P = 1.87 x d

Fig. 4: Macrograph, detection of incomplete penetration.

Ultrasonic testing with probe MWB70 N4 could show a reflector of max.3 mm in size in accordance with DGS, which means a reflection plane of around 7 mm, i.e., a separation of 0.7 mm in height.

Multi-wave ultrasonic probe SEK4 with an angle of incidence of 75 ° detects incomplete penetration in the weld at a distance of 48 mm of sound path from the point of incidence and a size of around 6 mm. The display at the screen was set to 10 mm of the reflector height (100%). The first signal displayed at the screen and moving in a horizontal direction is found at S = 33 mm. If this is multiplied with sin 75°, a projection of the sound path to the reflector, P = 32 mm, is obtained.

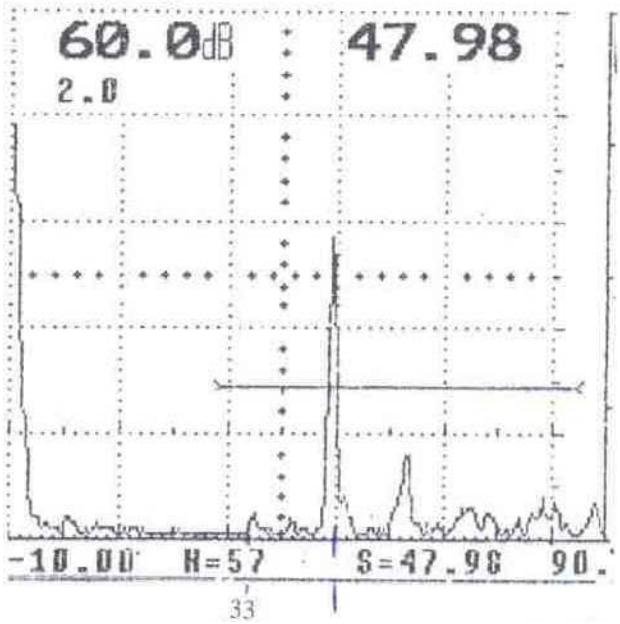
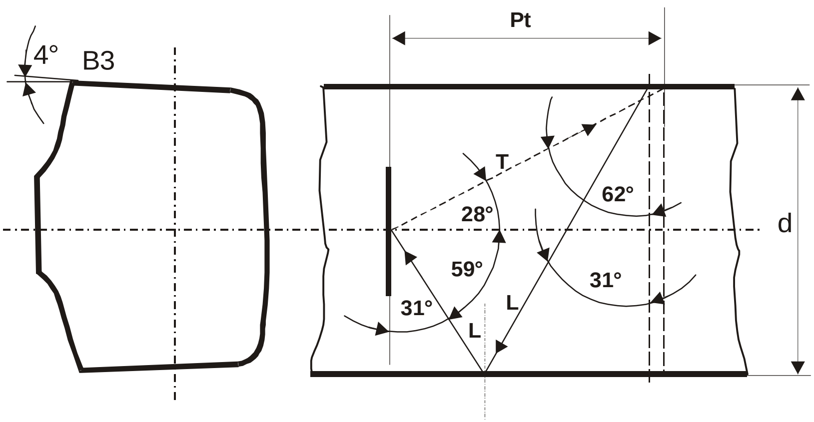


Fig. 5: Echo image of incomplete penetration obtained with multi-wave probe.

Figure 5 shows an echo image obtained with the multi-wave ultrasonic probe, which detected incomplete penetration at a distance of 33 mm from the probe centre and at a height of around 6 mm. 100% display at the screen is calibrated to 10 mm of the reflector height.

2. Testing of thick-walled welds: d > 50 mm

For testing of thick-walled welds having d > 50 mm ultrasonic probe SEW 31/62, 2 x 10 x 20 mm, 2 MHz, was chosen.



d = 70 mm   S = 1.02 x d   Pt = 0.94 X d

Fig. 6: Example of testing of thick-walled weld.

Figure 6 shows a directed reflector in a thick-walled weld to be detected by a longitudinal incident wave of 31°, which then transforms into a transverse wave to be intercepted by the transverse angle probe of 62°.
With thick welds the distance of the reflector from the point of incidence is great (around 2 d) and sound attenuation is above average. Consequently, a longitudinal wave with a frequency of 2 MHz and is directed to the test specimen at an angle of 31°. Sound will reflect from the bottom wall at the same angle as the longitudinal wave and fall on the reflector at an angle of 59°. Here it is, to a great extent, transformed to a transverse wave (80%) and propagates at an angle of 28° towards the incident face where it is intercepted by the transverse angle probe of 62°. Both probes are enclosed in the same housing.

2.1 Calculation of total sound path

Total sound path can be calculated using following equation

$$S_{LT} = [\,(1.5 \text{ x } d) : \cos 31^{o} + (0.5 \text{ x } d) : \cos 62^{o}\,) \text{ x } V_L \,/\, V_T\,] = 3.68 \text{ x } d \tag{4}$$

(the display is calibrated in the units of the longitudinal wave)

In practice the calibration is performed at the velocity of the transverse wave because with the built-in transverse angle probe of 62° the path in a plexiglass wedge can be compensated:

$$S_{LT} = 3.68 : 1.82 \text{ x } d = 2.02 \text{ x } d \tag{5}$$

As the display at the screen was calibrated in the echo method and the measurement is performed in the SE method, the result should be divided by 2 so that the position of the echo at the screen is obtained:

$$p = S_{LT} : 2 = 1.01 \text{ x } d \tag{6}$$

2.2 Distance of the reflector from the point of ultrasound incidence

Distance of the reflector from the point of ultrasound incidence can be obtained by

$$P_T = d / 2 \text{ x } \mathrm{tg}\, 62^{o} = 0.94 \text{ x } d \tag{7}$$

$$P_L = 1.5 \text{ x } \mathrm{tg}\, 31^{o} \text{ x } d = 0.9 \text{ x } d \tag{8}$$

2.3 Estimation of the reflector size

Sensitivity calibration shall be performed on a square-cut test piece, e.g. V1. With plates thicker than 70 mm, a correction read in Fig. 7 should be inserted.
In sensitivity calibration a correction due to sound attenuation due to a long sound path should be added. Transfer losses are negligible when using 2 MHz ultrasonic probes.

2.4 Practical example

Rails are arc-welded in a workshop and then aluminothermic-welded on site. It turned out in practice that a rail may be welded only at the edge whereas in the centre it may remain unwelded. In this case the flaw is perpendicular to the surface; therefore, it cannot be detected with a normal or SE probe or a single angle probe. The only solution is the tandem technique because both side rail faces are accessible. Such a procedure is declined by operators because two ultrasonic probes engage both hands and the probes shall be moved not only in the longitudinal direction but also in the transverse one. Also the acoustic contact with two probes seems to create problems.

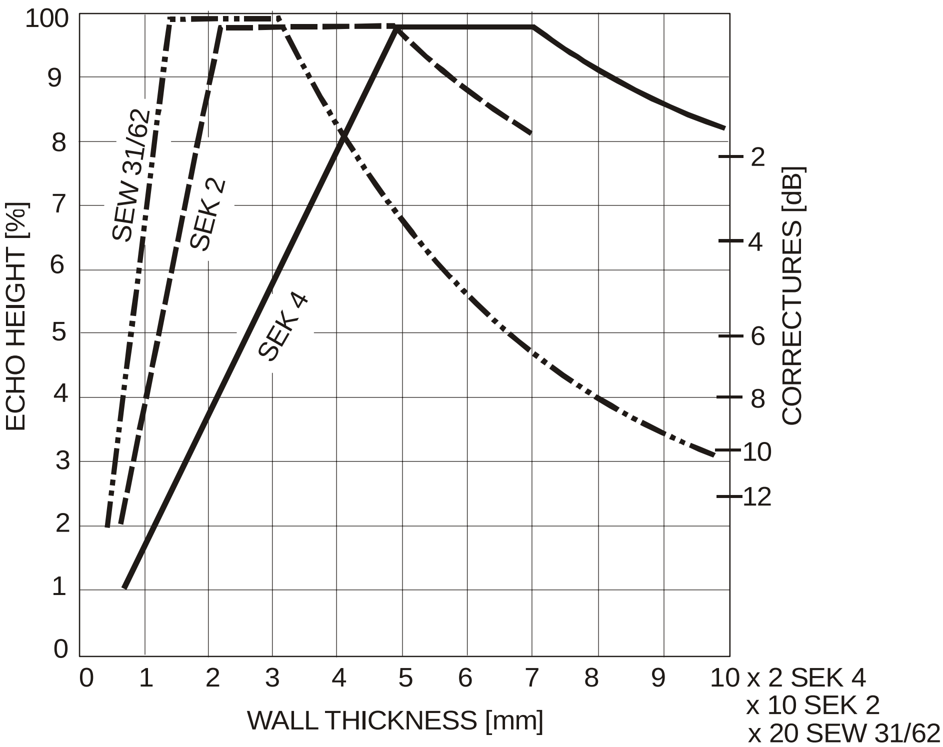


Fig. 7: Taking account of correction due to sound attenuation.

The use of multi-wave ultrasonic probe SEW 31/62 is simple, the probe engages only one hand, the acoustic contact is more reliable so that the distance and flaw size may be read directly from the display at the screen. The latter shall be calibrated at the transverse velocity to V1, and sensitivity to a square-cut piece of rail so that the calibration may encompass also transfer losses, which are great due to inclined walls.

Figure 8 shows an image of incompletely penetrated zone in a rail of 17 mm in size. The entire screen corresponds to 20 mm of the reflector height. A diameter of the rail head equals 70 mm (d = 70 mm).

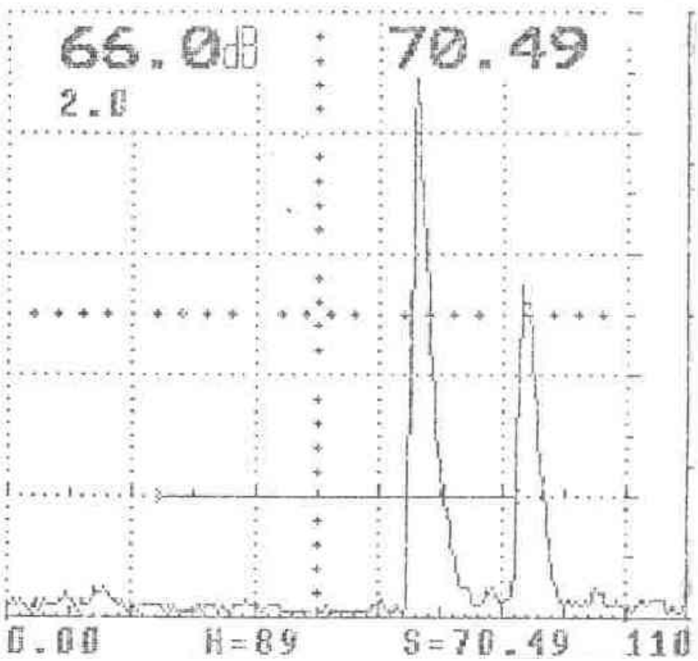


Fig. 8. Echo image of butt-welded rail with incomplete penetration.

Figure shows testing of a butt-welded rail with incomplete penetration perpendicular to the surface using a longitudinal two-wave probe of 31° and a 62° transverse probe enclosed in the same housing.
Sound path to the flaw:
S_{LT} = 70.9 mm = 1.012 x d. The display is calibrated in the transverse velocity.
The distance between the flaw and the point of sound incidence shall be determined using formula: P_T = 0.94 x d = 66 mm.

3. Conclusions

Advantages of multi-wave ultrasonic probes over the tandem technique:

- Only one hand and one ultrasonic probe are engaged.
- Problems of the sound contact are essentially smaller.
- The position and size of a reflector can read at the screen simultaneously.
- The range of measurement of plate thickness extends from 6 mm upwards and depends on the type of multi-wave probe used.

Limitations of application:

- The angle of sound incidence should be as stable as possible; therefore, it is recommended that the contact surface of the probe is protected by hard-metal inserts.
- The transfer losses strongly affect the estimation of the reflector size.
- The estimation of the reflector size depends on the perpendicular position to the surface and the reflector roughness.
- The linear dependence between the echo height and the height of the incomplete penetration is comparable if the sound beam falls on the reflector in its centre. It is applicable only with the reflectors the length of which is greater than the beam width. It is from this that depends the choice of a suitable ultrasonic probe with a suitable angle of incidence, i.e. 70°to 80°for probes SEK 2 of 2 MHz.

The testing method for the reflectors directed towards the surface is an addition to the tandem technique in case the latter is not feasible and the first is the only method usable.

4. References

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